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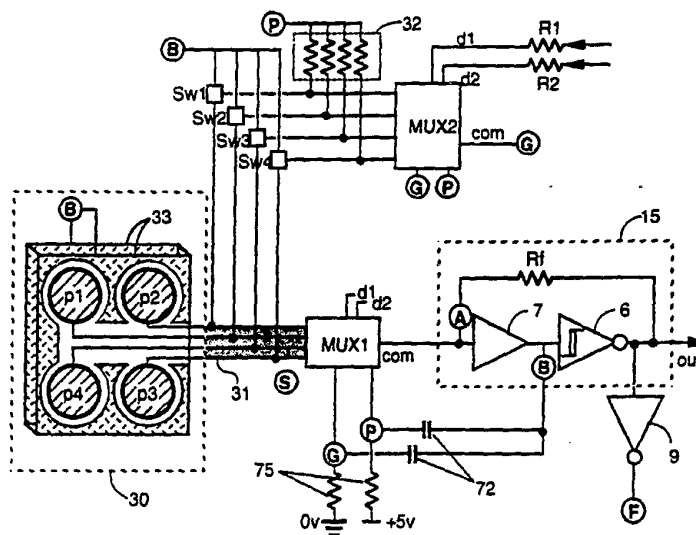
(57) Abstract

An imaging device whereby the internal characteristics and/or external dimensions and/or location of an object are determined by one or more sensors (p1-p4) and optionally one or more slave members which may be driven in or out of phase to the sensors and which transmit an effect to the sensors directly and via the object to be characterised. The sensors (p1-p4) vary the frequency or amplitude of an oscillator (15) which contains a buffer/follower amplifier (7) and a Schmitt trigger (6). The slave members are typically driven via an inverter (9). Unused sensor lines are buffered via buffered switches (Sw1-Sw4). Connecting lines to a plurality of sensors or slave members pass through multiplexers (e.g. MUX1) with buffered power rails (P, G) in order to eliminate the internal capacitance to the voltage supply and ground rails.

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DEVICE FOR DETERMINING THE PRESENCE AND/OR CHARACTERISTICS OF AN OBJECT OR A SUBSTANCE

This invention relates to a device for determining the presence and/or characteristics of an object or a substance.

Common ways of determining the position, size, shape and internal characteristics of an object are optical, inductive, ultrasound and capacitive. Sample uses for this are coin discriminators, quality control, industrial process control, and medical imaging. Inductive systems only tend to work well with metal objects and also tend to be temperature dependent. Additionally they cannot be made small enough to have very fine resolution. Optical systems are subject to interference by dirt and are frequently fragile, requiring exposed transparent lenses. Non-raster optical systems require good geometric matching of the sender receiver diodes to attain reliable and accurate imaging. Capacitive systems on the other hand are robust, cheap, can be made very small and low power, and do not require great mechanical precision to work well.

Conventional capacitive sensors, such as those used in keypads or industrial proximity sensors, either require separate electronics for each sensor pad, or give reduced sensitivity due to parasitic capacitance effects in the multiplexer used to switch each pad to the sensing electronics. Many existing systems operate with a tuned circuit driving each pad and detect the amplitude loss when this circuit is de-tuned by an object proximate to the pad. This circuit is very difficult to design so that pad variations (due to differences in geometry, or external influences such as dirt or moisture) can be automatically compensated for. This is because the tuned circuit would need to be re-tuned for each pad to keep the same sensitivity.

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Other systems use a transmit / receive technique based on
an x/y matrix. The presence of an object couples a verti-
cally scanned line to a horizontal one. These systems
suffer from an inherent theoretical lack of sensitivity,
and also from noise pick-up, as most of the receiver area
is not covered by the sensed object. Similarly x/y methods
where a single tuned circuit is applied by a multiplexer to
horizontal and vertical lines (looking for the crossing
point where a vertical and horizontal lines were touched)
lacks inherent maximum sensitivity possible given the area
of the sensing pad.

It is an object of the present invention to provide an
improved device for determining the presence and/or charac-
teristics of an object or a substance, which device allevi-
ates the aforementioned problems associated with such known
devices and is capable of giving greater control over the
shape of induced electric fields.

According to one aspect of the present invention, there is
provided a device for determining the presence and/or char-
acteristics of an object or a substance, said device com-
prising capacitive means, the capacitance of which is
changed due to the presence and/or characteristics of said
object or substance, and a circuit arrangement for detect-
ing said change in capacitance, characterised in that said
capacitive means comprises one or more sensors and one or
more slave members positioned relative to said sensor or
sensors and arranged to be driven in a predetermined phase
relationship with respect thereto, such that the change in
capacitance detected by said circuit arrangement is influ-
enced by electrostatic coupling between said one or more
sensors and said one or more slave members.

By this arrangement the characteristics of the object can

be determined by analysing the responses from the one or
more sensors. By using slave members, the sensor or sen-
sors will be affected by the degree of electrostatic cou-
pling between the one or more slave members and the one or
more sensors. Buffering means may be used to enhance the
sensitivity of the device and to shield the sensors from
unwanted external effects.

The invention thus makes use of capacitive means to cha-
racterise an object or substance by use of one or more
slave members, preferably in the form of specially shaped
pads or plates, that drive the material of the object or
substance capacitively and couple to a sensor which is also
preferably a pad or plate. These shaped plates may form a
physical matched filter. The short, medium and long range
effects of these plates can be exploited. The device, in
accordance with the invention, may be used to characterise
an object of any material or of a substance such as a
particular chemical.

It has been discovered that the invention can be used to
create a new effect which is the effective grounding out of
this capacitive coupling effect by objects at a far dis-
tance. This allows the presence of objects or substance to
be sensed at an order of magnitude greater distance than
previously possible and its characteristics determined
dielectrically.

The or each sensor is suitably driven by an oscillator of
the detection circuit, the sensor response being measured
either by a change in frequency or by a change in amplitude
of the output of the oscillator. Preferably the oscillator
circuit contains a Schmitt trigger. The device may include
means for storing the response of the or each sensor singly
and when the or each slave member is addressed, thus
building up a characteristic pattern of values. This stored

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information may be used in conjunction with pattern match-
ing, algorithmic processing, or simple switching of sensors
or slave members looking for effects above or below a
threshold.

When the sensor determines the frequency of the oscillator,
the frequency is affected by which sensor and which slave
member is addressed. The frequency output is typically an
analogue reflection of the object characteristics. Slave
members may be driven in or out of phase with respect to
the sensor with the same or a different waveform to the
sensor, but generally a square wave. The frequency of the
oscillator is affected by coupling of the currently select-
ed sensor to one or more slave members, either directly or
via the object being sensed.

Measurement by change in amplitude is suitable for certain,
particularly long range, applications. In this arrange-
ment, it is desirable to use a slave member which is inter-
nally frequency locked by the use of, for example, a ceram-
ic resonator. In this instance the sensor is constructed
to 'track' this frequency by the use of a Phase-locked loop
(PLL). Synchronous amplitude demodulation of the signal
received gives an extremely noise-immune system, but at a
higher cost than the frequency variant system more commonly
used.

Further noise reduction effects can be obtained by using a
square wave to drive a slave member and in the receiver
section only sensing the effect during a narrow time window
around the square wave transitions. This can be implement-
ed by measuring the slope of the oscillator triangle wave
during the window.

Accordingly, in another aspect of the present invention
there is provided a device for determining the presence

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and/or characteristics of an object or a substance, said
device comprising capacitive means, the capacitance of
which is changed due to the presence and/or characteristics
of said object or substance, and a circuit arrangement for
detecting said change in capacitance, characterised in that
said circuit arrangement includes a fixed frequency oscil-
lator, the amplitude output and/or phase of which is de-
pendent on said change in capacitance.

According to yet another aspect of the invention, there is
provided a device for determining presence and/or charac-
teristics of an object or a substance, said device compris-
ing capacitive means, the capacitance of which is changed
due to the presence and/or characteristics of said object
or substance, and a circuit arrangement for detecting said
change in capacitance, characterised in that said capaci-
tive means includes a plurality of sensors connected to the
circuit arrangement via one or more multiplexers the power
rails of which are connected to buffering means so as to
inhibit internal capacitance to said rails.

In a preferred arrangement, the buffering means includes a
voltage follower connected to the power rails via capaci-
tors. Unaddressed lines and sensors may be connected to
the voltage follower by extra switches, thus eliminating
the feed through capacitance effects in individual switches
in the or each multiplexer and allowing long lines to the
sensors on the same side of the PCB upon which the device
is mounted. The on/off ratio of these extra switches can
be improved by novel means in the form of an additional
impedance element from each sensor to the output of the
voltage follower.

In addition to buffering the multiplexer, the back-plane
may also be connected to the buffering means, so that not
only is the sensitivity increased but also the device can

be made very thin with connectors or electronics to one side. This allows a three dimensional or flexible design to be made. The buffering means have good radio frequency rejection properties being so near the sensing pads. The electronics driving the buffering means are band-pass in nature to increase this rejection and to cut down on spurious emissions.

In a preferred arrangement, the output of the or each multiplexer is fed to the voltage follower which has its power supply rails driven by a later stage low output impedance voltage follower. The voltage follower may include a dual-gate Mosfet and gate 2 of the Mosfet is suitably connected to a buffered point for optimal elimination of the input capacitance.

The device preferably includes means for measuring the effective charge rate or loss tangent from the or each sensor, which is dependent on the object and which if any slave member is addressed. This can be measured indirectly by having this effect control the oscillator.

In a specific arrangement, the internal characteristics and external dimensions of an object are determined by passing the object through a channel past the one or more sensors and slave members which are shaped to provide optimum identification of the object. The sensors and slave members may be separated electrically by extra sections located between them on a PCB and in the wiring to the PCB. The extra sections are driven by the voltage follower. The sensors and slave members may be etched onto one side of a double sided PCB, with one or more sensors and/or slave members being located opposite, typically detecting the thickness of the object. The outer faces of the PCB(s) are connected to the voltage follower thus isolating the sensing system from external effects especially RFI.

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One preferred embodiment comprises a single sensor and concentrically arranged buffer members and slave members. The slave members are driven via a multiplexer. The sensor may be circular and the buffer members and slave members may be shaped to form arcs of circles'matching that of expected circular shaped objects. This arrangement can then determine the number of objects present as well as their diameter, surface area, surface roughness and thickness. Alternatively the sensor may be square or otherwise shaped and the buffer members and slave members may have corresponding corners and straight sides extending around two, three or all sides of the sensor.

The device may be arranged such that the characteristics of an object can be determined whilst the object is moving or rolling and/or while it is stationary.

In one particular embodiment, the object is held stationary behind a solenoid controlled gate for recognition by the device and is released and redirected to a further solenoid gate or by 'pulsing' the first gate. This embodiment is suitable when the objects to be measured are coins or tokens in a vending machine. In this arrangement, the total coin detect mechanism can be made only slightly thicker than the coin detected. All electronic components can be located off-board. The circuitry is less expensive and less susceptible to temperature effects than non-capacitive systems. Additionally, it works with coins of non metallic nature, and it can be cheaply upgraded to much higher degrees of discrimination by simply adding more or smaller slave members. This allows more highly specified items to be used i.e. value tokens or security/identification tokens to be used in once only or highly secure applications.

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The device, in accordance with the present invention, may be used in many different applications. Examples of such applications are as follows:-

(i) to determine the two or three-dimensional shape of an object by virtue of a characteristic pattern of responses caused by the varying proximity of an object to each sensor or slave member;

(ii) to determine the pressure profile of an object, using a compressible membrane on top of an array of sensors;

(iii) internal scanning of objects to detect impurities or to remotely measure the dimensions of encapsulated objects;

(iv) for body surface imaging in medical applications such as retina contour mapping or joint measurement;

(v) as a vandal resistant or 'Through-Glass' keypad;

(vi) as part of a "pattern recognition" system utilising the responses of the various sensors;

(vii) for non invasive chemical dielectric testing;

(viii) for capacitive sensing at a distance from a VDU or LCD screen (i.e. as a 'touch-screen');

(ix) to read the dielectric characteristics embedded in an identity card;

(x) in much larger scale / longer range detection - for example to make a collision avoidance device for vehicles.

In this specification, the term 'Slave' is intended to cover any mechanism for transmitting an electrostatic signal to a sensor. Such devices are generally oscillating in a synchronous manner to the sensor in a predetermined phase relationship. They may be autonomous or directly controlled by an oscillator in the sensor.

The term 'capacitance' as used in this context is that

property which is measured by the effective charge rate or
loss tangent of a sensor.   This is most generally the
complex impedance of an object which is normally primarily
determined by the object's dielectric characteristics.

Additionally, a device or point which is 'buffered' is one
which is connected, directly or indirectly, to the output
of a voltage follower/buffer amplifier whose input is
generally, directly or indirectly, connected to a sensor
plate.

'Buffering means' generally consist of one or more voltage
followers connected to other components or plates.

The invention will now be described by way of examples
with reference to the accompanying drawings, in which:-
Figures 1 and 2 show respectively schematic elevational
and sectional views of one embodiment of the present inven-
tion;
Figure 3 shows schematically a circuit layout of the
embodiment in Figures 1 and 2;
Figure 4 shows a schematic layout of the part of the cir-
cuit shown in Figure 3;
Figure 5 shows a schematic layout of another embodiment in
accordance with the present invention,
Figure 6 shows one application of the embodiment shown in
Figure 5;
Figures 7a and 7b show diagrammatically the medium range
effect of the present invention and the equivalent capaci-
tive network, respectively;
Figures 8a and 8b show diagrammatically the long range
effect of the present invention and the equivalent capaci-
tive network, respectively;
Figure 9 shows the approximate long range detection effect
lines of another embodiment, iso-potential lines being
perpendicular to these detection effect lines;

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Figures 10 and 11 show two possible arrangements of sensor
arrays for use in three-dimensional surface or internal
imaging;

Figure 12 shows a cross - section of field lines of a
sensor array such as that in Fig. 10 or 11 when a curved
object is nearby;

Figures 13 and 14 show schematically two alternative modi-
fied circuit arrangements of a device in accordance with
the invention;

Figure 15 shows schematically a circuit arrangement in
accordance with another embodiment;

Figure 16 shows a plan view of an object being characte-
rised by a sensor array; ·

Figure 17 shows schematically another embodiment particu-
larly for coin/token sensing;

Figure 18 shows schematically a further embodiment wherein
queuing of coins/tokens is permitted;

Figure 19 shows schematically yet another embodiment for
sensing of rolling coins/tokens;

Figure 20 shows graphically a simplified statistical output
of the embodiments shown in Figures 14, 15 and 16;

Figures 21 & 22 show schematically the physical layouts of
two alternative embodiments suitable for chemical sensing;

Figure 23 shows a circuit arrangement of yet another embod-
iment of the invention; and

Figures 24 shows a technique for enhancing internal imag-
ing.

Referring firstly to the embodiment shown in Figs. 1 to 3,
a sensor plate 1 typically controlling the oscillation
frequency of an oscillator 15 containing a CMOS Schmitt
trigger 6 is buffered first by a low offset, low output
impedance voltage 7 which drives a buffer plate 2 and a
back shield plate 5. Slave members in the form of special-
ly shaped slave pads or plates 3a, 3b, 3c are switched to a
point (F) in the circuit to cause the frequency of oscilla-

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tion to change, usually decreasing, by coupling through the
air to the sensor plate 1. A switch 8 may be included to
cause the slave pads to be driven in phase (I), or out of
phase (O) via an inverter 9, and the slave pads are selec-
tively addressed via a multiplexer 10 controlled by micro-
processor 14 and selective address and inhibit lines 16.

The voltage follower 7 is shown in detail in Figure 4. The
voltage follower is designed to have a negligible input
capacitance by buffering the drain D of a dual gate Mosfet
Q1 and the power supply lines of the first stages, and for
best use a dual-gate Mosfet is used with an Ft of several
GHz. The source of this Mosfet Q, drives another high
speed follower stage composed of an npn transistor T_1 and a
pnp transistor T_2 with a current source C. These circuits
are designed for low capacitance at every internal node and
the PCB is laid out so the buffer lines drive the smallest
external capacitance to other lines on the board. Figure 4
also shows an optional potential divider circuit 19 which
provides a means to vary the fixed hysteresis level of the
Schmitt trigger 6 thus decreasing the frequency and reduc-
ing the effect of noise pulses.

As seen in Figure 2, as an object 16 moving down a track 13
overlaps the slave pads 3a, 3b, 3c and the sensor 2 simul-
taneously on the X axis it will couple more of the field to
the sensor and thus the frequency will change. This change
will be less if the object is further away from the sensor
on the Z-axis, has a smaller dielectric constant, or is
smaller or of a different shape than the selected slave
pad. As each slave pad is addressed the change in oscilla-
tion frequency is stored in the microprocessor 14, so as to
build up a pattern indicative of the characteristics of the
object 16.

The pads or plates 1, 2, 3a, 3b, 3c are etched on the same

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double sided PCB 4. The object has an external capacitance
to ground and as the circuit will have some connection to
ground albeit only capacitive, this can affect the measure-
ments.

The object is touching or almost touching the sensor/slave
pad arrangement, the capacitance to ground will be small
and can be made negligible by enclosing the object at this
point in a box 18 whose walls consist of shield plates
driven by the voltage follower. Plate 5 forms one wall of
this box. The box can then be lined with further slave pads
(on the inside of the other walls) shaped to characterise
the object spatially in three dimensions. Most usefully the
thickness can be determined with a slave pad 17 opposite
and parallel to the sensor. Extra sensors or slave pads
can be added to the left of this sensor/slave pad arrange-
ment to deal with the case of many objects on the same
track.

For thickness detection, a circular slave pad 17 (Figure 2)
located opposite the coin is turned on and driven in/out of
phase. On going out of phase the frequency of oscillation
decreases in proportion to the distance from the slave pad
17 to the top surface of the coin. The slave pad which is
measuring thickness is made physically smaller than any
coin expected and smaller than the sensor plate 1. This is
to allow an effect that is mainly due to thickness of the
coin coupling the slave pad 17 to the sensor 1 rather than
its diameter.

Figure 5 illustrates the layout of a device in accordance
with another embodiment of the invention having a sensor
arrangement 30 comprising four sensor pads p1-p4. The pads
p1-p4 are connected to multiplexers MUX1 and MUX2 via lines
31 on the same layer of PCB. The sensor pad to be ad-
dressed is selected by data lines (d1,d2). Both multiplex-

ers have power supply lines (P) and (G) which are buffered
by connection to the output of voltage follower 7 at buffer
point (B) via capacitors C1, C2. The multiplexers are
addressed by means of resistors (R1,R2) which are large
enough to ensure that the protection diodes inherent in the
multiplexers are not turned on and thyristor action does
not commence. Optionally the sensitivity is enhanced by
elimination of feed-through capacitance (approximately 0.25
pF for each multiplexer switch) by connecting unused pads
to the buffer point (B). This is effected by the group of
switches (Sw1 - Sw4) whose power supply lines themselves
are buffered. This prevents non-selected pads from affect-
ing the frequency of oscillation when touched. If slave
members are used, they are connected via inverter 9, to,
for example point (F) in the circuit of Figure 5.

The device makes maximum use of buffer/follower techniques
so that the multiplexer arrangement, having its power lines
and unused input lines buffered, is transparent electrical-
ly. This is accomplished by the buffering of the power
lines to multiplexer MUX1 which cancels the capacitance
(approximately 4 pF) of each analogue input pin to the
rails and the combined capacitance (i.e. approximate number
of analogue switches multiplied by 4pF) at the common pin.
The unused input lines are connected to the buffer point
(B) through multiplexer MUX2, the rails of which are also
buffered for capacitance cancellation. This has the effect
of cancelling the feedthrough capacitance of multiplexer
MUX1. The feedthrough capacitance of the switches SW1-SW4
is cancelled by having them addressed and pulled to the
buffer by means of one of resistors 32. The switches them-
selves have buffered rails which cuts down on parasitic
capacitance from the switches to the rails and allows the
tracking of lines to or from the switches to be near the
sensors.

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The first stage of the oscillator 15 is designed to have an
extremely low input capacitance so that any capacitive
temperature effects at this point are made negligibly. This
also allows smaller sensor pads to be used which means less
noise is picked up. These very small pads still have high
sensitivity due to a focussing effect and shielding from
background capacitance caused by a common shield plate 33
also connected to the buffer point (B) and located behind
all the pads and around each pad (p1-p4).

Because only one oscillator arrangement is required, a high
investment can be made in it. The device is therefore
sufficiently sensitive and stable that it can be used for
multi-pad dielectric sensing of chemicals, for example in
routine blood analysis. It is also so sensitive that
single sided PCB technology can be used with resultant
costs saving due to the lack of plated-through holes and
the potential use of carbon film/membrane board techniques.
This also can result in a much thinner design.

Figures 6a and 6b illustrate one of many possible uses of
the embodiment described in Figure 5 as a 'through-glass'
keypad for public access information systems. The whole
device is mounted on the inside of a plate glass window 40.
The first 'layer' is typically legends and artwork on a
sticker 43 visible through the glass indicating key posi-
tioning and giving basic operating instructions. Bonded to
the back of this is the main sensor PCB 30, which is double
sided, consisting of the sensor pads (p1-p4 etc), layer 44
and the shield layer 33 as shown in Figure 5. This is
connected to a separate PCB 42 containing the electronics
and providing a computer interface and connection 43 -
typically keyboard emulation or RS232. The electronics are
sealed and protected in a cover 41 which is typically
moulded ABS.

Substantially the same embodiment can be used as a 'through-book' sensor, or as a vandal resistant keypad for e.g. door entry systems on blocks of flats. The main variation is the material in front of the sensors, which can be anything conductive, but is paper in the first instance and typically a thick layer of polycarbonate in the second instance above.

As shown in Figs. 7 and 8, as well as the short range effects described so far, the device is also sensitive to medium range and long range effects.

In the medium range case shown in Figure 7 with an object 35 at a distance of approximately the sensor's shortest dimension away, the effect of the slave on the sensor will be affected both by the capacitance from the object to sensor (Cs) and to slave pads (Cf) and also by the object's capacitance to ground (Cg) which causes a potential divider 36 to be set up as shown. This capacitance is of the same order of magnitude as the capacitance to the plates on the sensor board - i.e. $Cg \backsimeq Cs \approx Cf$.

In the long range case shown in Figure 8, the capacitance to ground is so large that the object 35 is hardly driven at all by the capacitance Cs to the slave pad (F) and thus the object 35 is not relaying much of this effect to the sensor. This can be exploited for greater range by making the slave pad to sensor distance much greater (of the order of ten times the sensor's greatest diameter). Typically without an object in the field, the sensor's frequency is changed by only a few percent by action of the slave pad via the linkage capacitance (Cl). This change will be diminished significantly by the aforementioned capacitive potentiometer effect when an object is at a range of approximately the sensor to slave pad distance. The effect is that of the field 40, as shown in Figure 9, being par-

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tially absorbed. In practice this means having separate
sensor and slave pad boards placed at a distance apart on
the X axis at an equal distance to the required distance to
sense presence along the Z axis. The in/out of phase
inverter can be of any waveshape as long as it increases or
decreases the frequency of the sensor.

The amplitude of the waveshape in the slave pad should be
increased by using higher voltage supply rails until a
suitable signal to noise ratio is observed, generally at
least one percent change in frequency between the slave pad
being active and inactive. For best long range determina-
tion, the slave pads are switched in and out of phase at a
repetitive rate and correlation and synchronous demodula-
tion methods are used to determine the presence and exact
location of an object. The distance at which this "far"
field effect happens can also be changed by either provid-
ing an earthed plane near the object or another plate
driven by an out of phase signal with respect to the sensor
with an adjustable amplitude. This signal can be a square
wave whose switching points are at the peaks of the trian-
gle wave generated by the oscillator 15.

This effect can also be utilised in materials where, in-
stead of air being the dielectric, a low dielectric medium
is used and for the "object" a relatively high dielectric
mass is located inside the material. The high dielectric
mass will be earthed if it is actually in the soil; or
similarly if the mass on the further side has a large
capacitive coupling to earth; or if an earthing plate is
arranged on the back of the "object" to provide this; or if
a "super earth" effect is generated by driving a slave
plate on this back with a signal out of phase with the
sensor. This signal can then be made greater or smaller
which will move the long range effect toward or away from
the sensor. This enables materials to be looked into and

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the internal characteristics determined further. This
should be combined with known effects of placing slave pads
at different distances from the sensor for internal throw-
ing of the field.

Another embodiment uses the system for a collision avoid-
ance device for automobiles. It uses two pads as in figure
9. This uses primarily the long and medium range effects
described above. One of the two pads is used as a sensor,
the other as a slave, which may be driven in or out of
phase, with or without amplification. Possibly, the two
pads can alternate as sensors and slaves to monitor any
near field effects, which would differentially affect the
pads according to object distance on both the X and Z axes.

Figs. 10 and 11 illustrate two examples, each comprising a
plurality of multiplexed sensors S used without slaves
wherein the subsequent image processing is made easier by
arranging the sensors in symmetric grids.

Figure 12 illustrates the effect on the field surrounding
each sensor in a matrix 50 caused by the approach through
air of a curved object 35 with a high dielectric.

Figure 13 shows a circuit to improve the buffering of the
multiplexer (MUX1, MUX2) power supply rails (P) (G), so
that the substrate capacitance of the switch to the rails
is reduced. The more accurately voltage follower 87 can
achieve a 1:1 input:output ratio the lower the effective
capacitance between each switch input and the substrate and
the common pin to substrate becomes. The ratio approaches
1:1 if the output impedance of the voltage follower is much
smaller than any impedance being driven to an effective AC
ground. Where the variations in input capacitance causes a
change in oscillator frequency the voltage follower must be
capable of working at much higher frequencies than the

oscillator. This also means that the output impedance of
the voltage follower must be as low as possible to drive
any stray capacitance. Unfortunately voltage followers
generally trade off accuracy of input:output ratio against
low output impedance which means that a compromise has to
be made.

A circuit configuration using a second voltage follower 86
is shown which avoids the need for this compromise. The
configuration allows a very high accuracy voltage follower
87 to be used in the first stage because it only has to
drive a large impedance created by the second, lower accu-
racy, voltage follower 86 which has a low output impedance.
This configuration is hereafter referred to as 'double
buffering'.

For example the first stage voltage follower 87 might
follow its input to an accuracy of one part in a thousand
and the second stage 86 to one part in a hundred. To
supply 5V power to the multiplexers, two resisters 84 and
85 in series are connected between 5V and the VDD pin. The
resistor 84 connected to 5V has its other pin driven by a
capacitor 83 to the second stage voltage follower 86. This
makes the resistor 85 to the VDD pin appear approximately
one hundred times larger at the VDD pin. The VDD pin is
then driven by the first stage voltage follower 87 through
a capacitor 82. The first stage voltage follower 87 is
thus not significantly degraded since it is driving a large
impedance. The same technique is applied to the 0v rail.

If the second stage voltage follower 86 has a bipolar input
it will generally have an output impedance dependent on its
input impedance given by approximately 1/current gain.
Thus if the second stage voltage follower 86 is driven by
the output impedance of the first stage voltage follower
87, the second stage voltage follower's output impedance

will be very small (1/current gain of first stage) so it
also will not be seriously degraded by driving a resistor
connected directly to the rails.

Alternatively the resistors 84 can be replaced with a
constant current source or the inputs of power supplies
which are made to follow and supply the rails of the multi-
plexer can be double buffered.

For a bandpass action the resistors 84 and 85 can be
replaced with tuned circuits supplying the rails of the
multiplexers. This is an effective way of cutting out
input noise of a different frequency as it sees a large
capacitance to the substrate in the multiplexers that is
not buffered out.

The two voltage followers 87 and 86 can be either driven
from the same input or one can drive the other as shown in
the diagram.

This buffering technique can be extended to triple and
higher orders of application to improve the buffer
amplifiers in terms of follower action at higher frequen-
cies and of reducing output impedance.

Figure 14 shows another method of improving the multiplexer
action by reducing the effective co-capacitance C across
each switch. An additional impedance C2 approximately one
thousandth of the value of said co-capacitance is added
from each sensor pad p1 to a voltage follower 7. This
reduces unwanted feedthrough of capacitance from an unse-
lected pad to the common via the co-capacitance C3. In
general an unselected sensor will add a capacitance C1 to
the common whose value will be in series with the co-
capacitance C3. The co-capacitance C3 is approximately
0.2pF. However with an almost 1:1 follower amplifier

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driving one pin of an additional capacitor C2 and the other
pin connected to the sensor the equivalent capacitance of
the unselected pad on the input of the voltage follower is

$$C_{equiv} = \frac{C_1 C_3}{C_1 + C_2 + C_3}$$

If the additional capacitance C_2 is large with respect to
the co-capacitance C_3, the unselected pad capacitance to
the external world C3 is reduced by $\frac{C_1 C_3}{C_2}$.

In effect the additional impedance C2 forms a voltage
divider with the impedance of a signal source driving a
sensor pad, thus making the impedance of the 'off' switch
greater. A tuned impedance at this point maximises the
effect.

Figure 15 illustrates a technique whereby sensor plates p1
can be used with individual back plates 90 which are
switchable via a multiplexer MUX3 either to the voltage
follower 7, making them into shield plates, or to signals
in other phases via mux lines 92 thus making them into
slaves. This can result in an imaging system capable of
taking very complex readings but taking up minimal space.
The back plates are typically each driven by a second
simple voltage follower 91. Typically the sensor plate p1
will be significantly smaller than the back plate 90, thus
allowing co-capacitance reduction by the method described
in Fig. 14.

Figure 16 shows a rectangular array of sensors characteris-
ing an object where the level of response from each sensor
is displayed as a degree of shading. A characteristic
pattern such as this may represent:

   (i)   the shape of an object (stronger response given by
closer proximity at that point);

   (ii)   the pressure profile of an object (where a compres-
sive membrane of some sort, such as expanded silicon rub-
ber, is placed above the sensor array and optionally made
conductive on the top surface then the proximity of the top
surface to the sensor is proportional to pressure and
affects the sensor response);

(iii)   the internal construction of an object (if the
dielectric varies - areas of lower sensor response may
indicate voids in a moulding for instance, or areas of
higher response may indicate un-cured areas in an
adhesive).

The embodiments shown in Figs. 17 to 19 are intended for
use as coin/token sensors.

The embodiment in Fig. 17 uses only the short and medium
range effects for sensing the diameter, surface area,
roughness, and thickness of a coin or token. It also de-
tects the presence of a following second coin near or
touching the first coin. This technique allows tokens to
be used that are non-metallic. It consists of a partially
enclosed buffered box with a "thickness" slave pad opposite
the sensor on a parallel plate with the back sides of both
plates buffered, as shown in Figure 2.

The arrangement of sensor and primary slaves is shown in
Figure 17. The arc-shaped slave pads 3a, 3b, 3c are ap-
proximately the diameters of the various coins to be iden-
tified. They are tracked with fine lines to a ribbon cable
11 in which every alternate wire is connected to the buffer
point (B), which may also exist as fine tracks between the
slave pads on the PCB. A through-plated hole 20 leads to

-22-

tracking on the buffer plane 5.

Slave pad 3d is a second coin detector. If a second coin is
touching (or nearly touching) the first coin, its presence
will be detected when slave pad 3d is switched on. When
this happens a strong effect will be coupled to the second
coin and on through the first coin to the sensor. Slave pad
3e and its associated ground plate show the long range
effect, but isolated to the region confined between the two
parallel buffer plates formed from the backs of the plate
containing the sensor and the opposing parallel plate
containing the thickness slave pad (equivalent to the
"buffered box" in Figure 2). The slave pad 3e can be made
to have an adjustable "superground" effect by driving it
with a variable out of phase voltage.

In the embodiment of Figure 18, the sensor pad and slave
pads are made optimally in a particular shape such that on
the side of mechanical coin stop 12 the minimum intersec-
tion of the smallest and largest coin is used - i.e. an arc
that fits the largest coin 34. The shape of the sensor arc
away from the stop is indirectly determined by the smallest
coin that is to be identified as this will determine the
arc of slave pad 3a.

For surface area sensing, all slave pads are turned off
except for the outer one which lies outside the diameter of
the coin/token. Thus field lines radiate from anywhere on
the surface of the token. The frequency of the oscillator
is decreased in proportion to this surface area.

For a number of coins in a stack, either multiple sensors
can be used in a row or, if the coins are stationary and
physically touching, a row of slave pads can be turned on.
For example, if they are turned on in phase they will
couple through coins sitting above them and through other

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coins, eventually to a coin above the sensor. The slave
pad determining coin thickness locates coins at a distance
from the sensor with an analogue effect. Several slave
pads can be used to increase precision.

The information received by switching the slave pads on and
off and in and out of phase is seen as an effect on the
sensor plate. Normally for low cost construction this is
in the form of a frequency derived from a Schmitt trigger
oscillator 15 (Figure 3) which has a low capacitance input,
low impedance output buffer 7 before the Schmitt trigger 6.

The frequency obtained when each slave pad is switched on
in turn (in or out of phase) is measured, and may be
stored. The pattern of frequencies thus observed characte-
rises a coin or other object. The pattern may incorporate
frequencies derived when slave pads to one side are
switched on (a good measure of diameter) and/or those
opposite (a good measure of thickness). A comparison with
previously stored values or limits can be made by algo-
rithms ranging from complex pattern matching to simple
thresholding (which determines which slave pads are over-
lapped). This comparison can then be used to make
accept/reject decisions. Identification without the
"thickness" slave pad may be advantageous in that it allows
identification to be performed simply by placing the
coin/token onto a flat detector.

If the coin is identified in motion rather than when
against the gate then the slave pads are shaped as in
Figure 19 to attain a matched filter. If more than one
coin is allowed to stack behind the gate then the slave
pads should be shaped as in Figure 18. The reason being
that the second coin should not be allowed to overlap the
slave pads (3a-3c) which mainly measure diameter.

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Figure 20 shows graphically a simplified statistical output
of the coin discriminator embodiment shown in figures 17,
18 and 19. Each horizontal axis 51 in the diagram repre-
sents the frequency measured at the sensor with a particu-
lar slave turned on. Each normal curve 52 represents the
measured frequencies of a large number of samples of a
particular type of coin with the same slave turned on.
Each type of coin can therefore be characterised as shown
by the combination of frequency responses from all the
slaves. The 'accept window' (i.e. allowable frequency
deviation from the mean) can be set from the width of the
normal curve and the desired percentage of correct coins
rejected vs fake coins accepted.

Referring now to Figure 21, there is shown an embodiment
suitable for chemical dielectric measurement (of one or
many containers). This embodiment consists of a plurality
of sensor devices 37, each comprising sensor pads (S),
buffer areas (B), and slave pads (F) and being positioned
optimally for the effect that it is desired to sense. The
chemical 38 to be tested may overlay one or more of the
sensor devices 37. If multiple sensors, buffers or slave
pads are in close proximity to the same container, differ-
ences in density and dielectric can be measured in differ-
ent places in the container.

Figure 22 shows another embodiment for chemical dielectric
measurement, which has a cylindrical slave pad F forcing
the field lines to cross most of the chemical 38 to be
tested. Other arrangements with different geometries of
sensors, buffers and slaves attached to a container for
containing the chemical to be tested may alternatively be
utilised.

Figure 23 shows the circuit schematic for an amplitude-
modulated version of sensor and slave arrangements de-

scribed previously. If slave members (F) are being used
they are connected, via a multiplexer if necessary, to a
fixed frequency oscillator 68 and a voltage amplifier 69
via a resistive, capacitive, or inductive coupling 70. The
oscillator 68 may be locked by the use of a crystal, for
instance. The sensor (S) is connected (possibly via a
multiplexer) to the voltage follower 7 as before, and then
to an amplifier 62. The amplified signal is then passed
through a narrow band-pass filter 63 (e.g. 455 KHz ceramic)
and amplified again by amplifier 64. The signal is then
rectified 65 by one of several means e.g. half wave, full
wave, PLL quadrature demodulation or a multiplier driven by
oscillator 68 and appropriate phase shift. Finally an op-
amp 67 is used to give a high-gain output. As before, the
slave (F) couples to the sensor (S) capacitively through
the environment. If the arrangement is used as an array of
multiplexed sensors without slaves then the oscillator 68
is connected directly to the sensor (S) via a resistive,
capacitive, or inductive coupling 70 and a direct link 71.

Figure 24 shows a technique for enhancing internal imaging,
particularly for impedance tomography, whether it be me-
chanical or electrical impedance. The description follows
for mechanical impedance. If an object 73 is suspended in
a medium 72 of similar, but not identical, dielectric
constant a capacitive sensor array 74 will be unable to
image the object if it is static. If, however, a modula-
tion source 75, such as a loudspeaker, is used then the
object 73 can be made to vibrate or resonate within the
medium 72. The use of a correlation detector 76 will than
allow the object to be picked out of the surrounding medium
by virtue of its movement. The object and the medium must
be significantly mechanically dissimilar, particularly in
their rigidity, for this to work. The same technique will
work for to objects with different electrical impedances
but similar dielectric constant if the modulating source 75

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provides an oscillating magnetic field. Similarly a single
pulse or collapse of an external field whether
electrostatic, magnetic, mechanical or optical can be used
to distinguish an object from the medium or enhance its
resolution.

Whilst particular embodiments of the present invention have
been described, various modifications will be envisaged
without departure from the scope of the invention as de-
fined in the appended claims. For instance, the sensor,
buffer and slave members may be any suitable shape accord-
ing to the application in which the device is intended to
be employed. For example, as shown in Figures 1 and 7, the
sensor is square-shaped and the buffer and slave members
have corresponding corners and straight sides. On the
other hand, in Figures 14, 15 and 16 the sensor is circu-
lar and the buffer and slave pads are arcuate as described
hereinabove. They may also be arranged in any suitable
physical arrangements, such as in a plurality of shapes,
for example parallel lines, in a zig-zag formation. In
another example, a device in accordance with the present
invention may be used for detecting objects through water
by use of slave members to set up a potential gradient in
the water to the sensor, which is disturbed by the advent
of an object to be detected. In yet another example suit-
able for chemical dielectric testing in a container, the
device may include a circular sensor and concentric buffer
members and slave members driven in or out of phase with
the sensor. The device is located inside the container
with another sensor outside the container, thereby sensing
the change in dielectric in vitro on one side of the inside
sensor giving a gradient change from that sensor to the one
located outside and thus positional information on density
and composition of the chemical.

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CLAIMS

1.   A device for determining the presence and/or char-
acteristics of an object (16) or a substance (38), said
device comprising capacitive means (1,3a,3b,3c), the capac-
itance of which is changed due to the presence and/or
characteristics of said object (16) or substance (38), and
a circuit arrangement for detecting said change in capaci-
tance, characterised in that said capacitive means
(1,3a,3b,3c) comprises one or more sensors (1) and one or
more slave members (3a,3b,3c) positioned relative to said
sensor or sensors (1) and arranged to be driven in a prede-
termined phase relationship with respect thereto, such that
the change in capacitance detected by said circuit arrange-
ment (15) is influenced by electrostatic coupling between
said one or more sensors (1) and said one or more slave
members (3a,3b,3c).

2.   A device as claimed in claim 1, wherein said capac-
itive means (1,3a,3b,3c) includes a plurality of sensors
(1) and/or a plurality of slave members (3a,3b,3c), and
said device includes one or more multiplexers (MUX1, MUX2)
arranged to address the sensors and/or slave members se-
quentially or simultaneously.

3.   A device as claimed in claim 2, wherein the power
rails (P,G) of the or each multiplexer (MUX1, MUX2) are
connected to buffering means (7,C1,C2) so as to inhibit
internal capacitance to said rails (P,G) and effectively
making emerging lines buffered.

4.   A device as claimed in any preceding claim, wherein
one or more buffering members (2,5) are positioned relative
to the sensor or sensors (1) so as to enhance the sensitiv-
ity of the device and to shield the sensor or sensors (1)
from unwanted external effects.

5.   A device as claimed in any preceding claim, wherein
the circuit arrangement (15) includes an oscillator (15)
having an output frequency dependent on the change in

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capacitance of said capacitance means (1,3a,3b,3c).

6.   A device as claimed in any one of claims 1 to 4,
wherein the circuit arrangement (15) includes an oscillator
having an output amplitude dependent on the change in
capacitance of said capacitive means.

7.   A device as claimed in any preceding claim, includ-
ing means for storing the output of said detecting circuit
arrangement (15) in respect of the or each sensor (1) and
the or each slave member (3a,3b,3c) when driven, such that
said stored outputs can be used to determine the presence
and/or characteristics of said object (16) or substance
(38).

8.   A device as claimed in any preceding claim, wherein
the capacitive means (1,3a,3b,3c) are positioned on one
surface which the object (16) is adjacent in order to
determine its characteristics.

9.   A device as claimed in claim 8, wherein additional
capacitive means (17) are located on a second surface
positioned on the side of the object (16) remote from said
one surface.

10.   A device as claimed in any preceding claim, wherein
the capacitive means (1,3a,3b,3c) comprises one sensor (7)
and a plurality of slave members (3A,3B,3C) arranged gener-
ally concentrically around said sensor (1), and includes
one or more buffer members (2,5) arranged relative to the
sensor (1).

11.   A device as claimed in any preceding claim, includ-
ing means (12) for retaining the object (16) in a station-
ary position whilst its characteristics are determined.

12.   A device as claimed in any one of claims 1 to 10
wherein said capacitive means (1,3a,3b,3c) are arranged so
as to determine the presence and/or characteristics of an
object (16) as the object moves past said capacitive means.

13.   A device as claimed in any preceding claim, wherein
the one or more sensors (1) and one or more slave members
(3a,3b,3c) are etched on one side of a double-sided PCB,

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and an additional slave member is etched on a further
double-sided PCB directly opposite said one or more sensors
(1) so as to determine thickness of said object (16), outer
faces of the two PCBs being connected to buffering means
(7).

14.   A device as claimed in any preceding claim for use
in chemical dielectric testing, wherein an arrangement of
one or more sensors (S), one or more slave members (F), and
one or more buffer members (B) are located beneath, on the
outer side or on the inside of one or more containers for
containing the chemical to be tested.

15.   A device for determining presence and/or character-
istics of an object (16) or a substance (38), said device
comprising capacitive means (p1-p4), the capacitance of
which is changed due to the presence and/or characteristics
of said object (16) or substance (38), and a circuit ar-
rangement (15) for detecting said change in capacitance,
characterised in that said capacitive means (p1-p4) in-
cludes a plurality of sensors (p1-p4) connected to the
circuit arrangement (15) via one or more multiplexers
(MUX1) the power rails (P,G) of which are connected to
buffering means (7,C1,C2) so as to inhibit internal capaci-
tance to said rails (P,G).

16.   A device as claimed in claim 15, wherein the buff-
ering means (7,C1,C2) includes a voltage follower (7)
connected to the power rails (P,G) via capacitors (C1,C2).

17.   A device as claimed in claim 18, wherein unad-
dressed lines and sensors (p1-p4) are connected to the
voltage follower amplifier (7), thus inhibiting feed-
through capacitive effects in individual switches in the or
each multiplexer and allowing long lines to the sensors in
the same side of a PCB upon which the device is mounted.

18.   A device as claimed in claim 15 or 16, wherein the
output of the or each multiplexer (MUX1) is fed to the
voltage follower (7) which has its power supply rails
driven by a later stage low output impedance voltage fol-

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lower.

19.   A device as claimed in claim 16, 17 or 18, wherein said voltage follower arplifier (7) includes a dual-gate Mosfet Q, gate 2 of which is buffered for optimal elimination of input capacitance.

20.   A device as claimed in any one of claims 16 to 19, wherein an additional impedance (C2) is connected between each sensor (p1-p4) and the output of said voltage follower (7) so as to reduce the feedthrough effect of external capacitance on selected sensors via the co-capacitance of a switch of said or one said multiplexers which is turned off.

21.   A device as claimed in claim 15, wherein the buffering means includes two voltage followers (87,86) connected in series, one being designed particularly for high precision and the other for low output impedance.

22.   A device as claimed in any one of claims 16 to 21, wherein the power rails (P,G) of said one or more multiplexers (MUX1) are connected to constant current sources and are driven by a capacitor to the output of said voltage follower (7).

23.   A device as claimed in any one of claims 15 to 22, wherein said plurality of sensors (p1-p4) is provided with back plates which may be switched to be slave members or shield plates.

24.   A device as claimed in any preceding claim, wherein the one or more sensors (1) and one or more slave members (3a,3b,3c), if used, are etched on one side of a PCB.

25.   A device as claimed in any one of claims 15 to 25, wherein one or more additional components of the device are connected to said buffering means (7,C1,C2), so as to allow all components of the device, including the sensors (p1-p4), to be located on one side of a PCB without the use of through-holes.

26.   A device as claimed in any preceding claim, including means (15) for measuring the effective charge rate or

loss tangent from the or each sensor.

27. A device as claimed in any one of claims 16 to 26, wherein buffering members connected to said voltage follower (7) are located behind the sensors (p4-p4) and/or said one or more multiplexers (MUX1) and/or a first stage of said voltage follower.

28. A device as claimed in any one of claims 15 to 27, wherein the output of said buffer/follower amplifier (7) is connected to a Schmitt trigger (6), and circuit means (19) are provided between said amplifier (7) and said Schmitt trigger (6) to vary the hysteresis level of said Schmitt trigger (6).

29. A device for determining the presence and/or characteristics of an object (16) or a substance (38), said device comprising capacitive means (1,3a,3b,3c), the capacitance of which is changed due to the presence and/or characteristics of said object (16) or substance (38), and a circuit arrangement (62-70) for detecting said change in capacitance, characterised in that said circuit arrangement (62-70) includes a fixed frequency oscillator (68), the amplitude, output and/or phase of which is dependent on said change in capacitance.
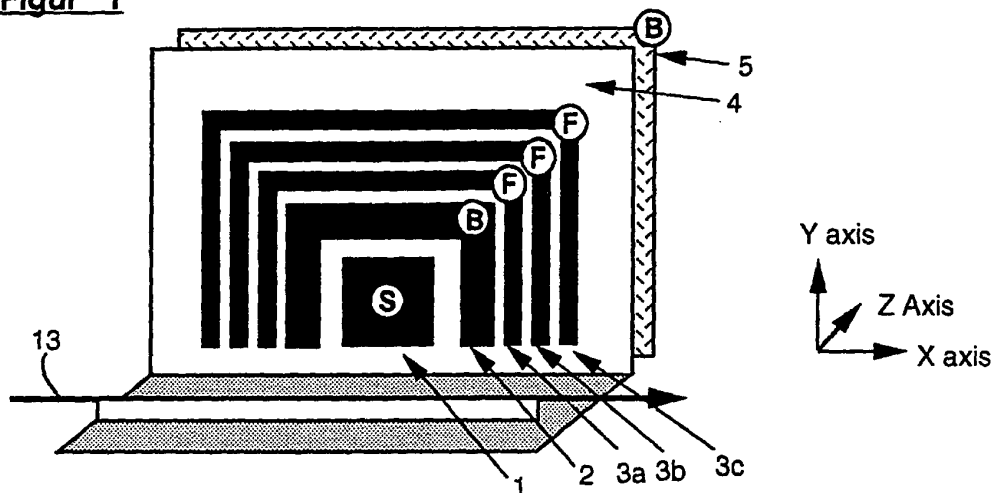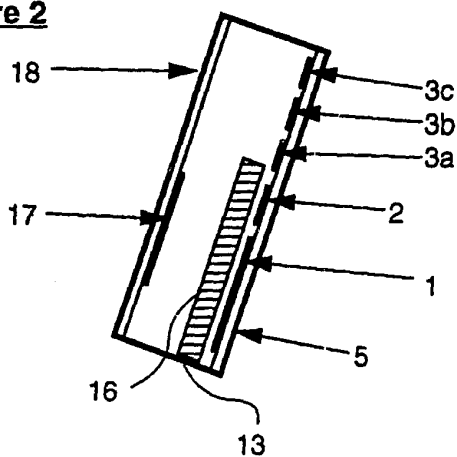
Figur 1

Figure 2

Figure 3
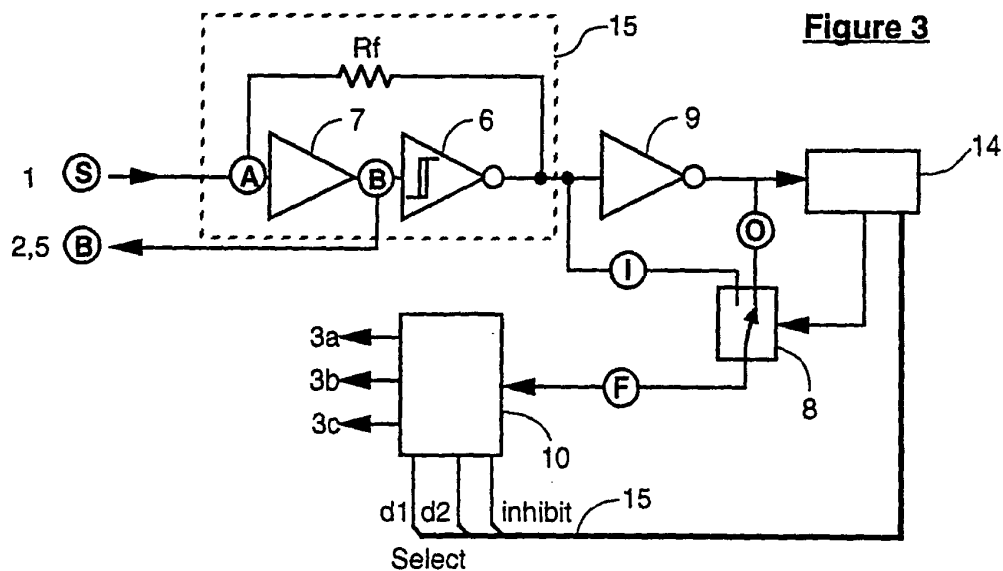
2/10

Figure 4
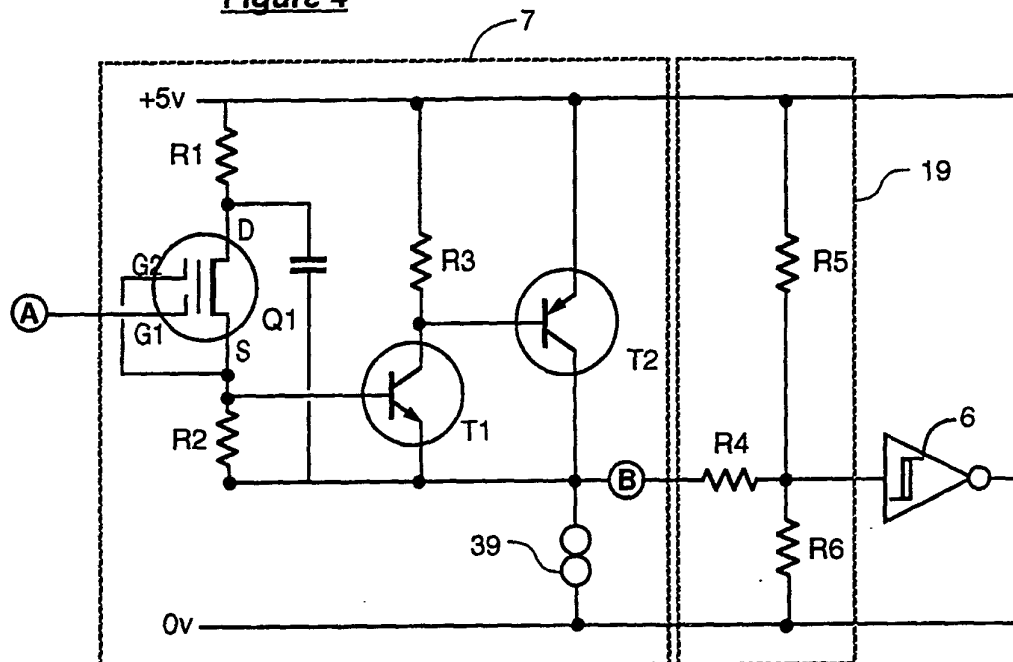
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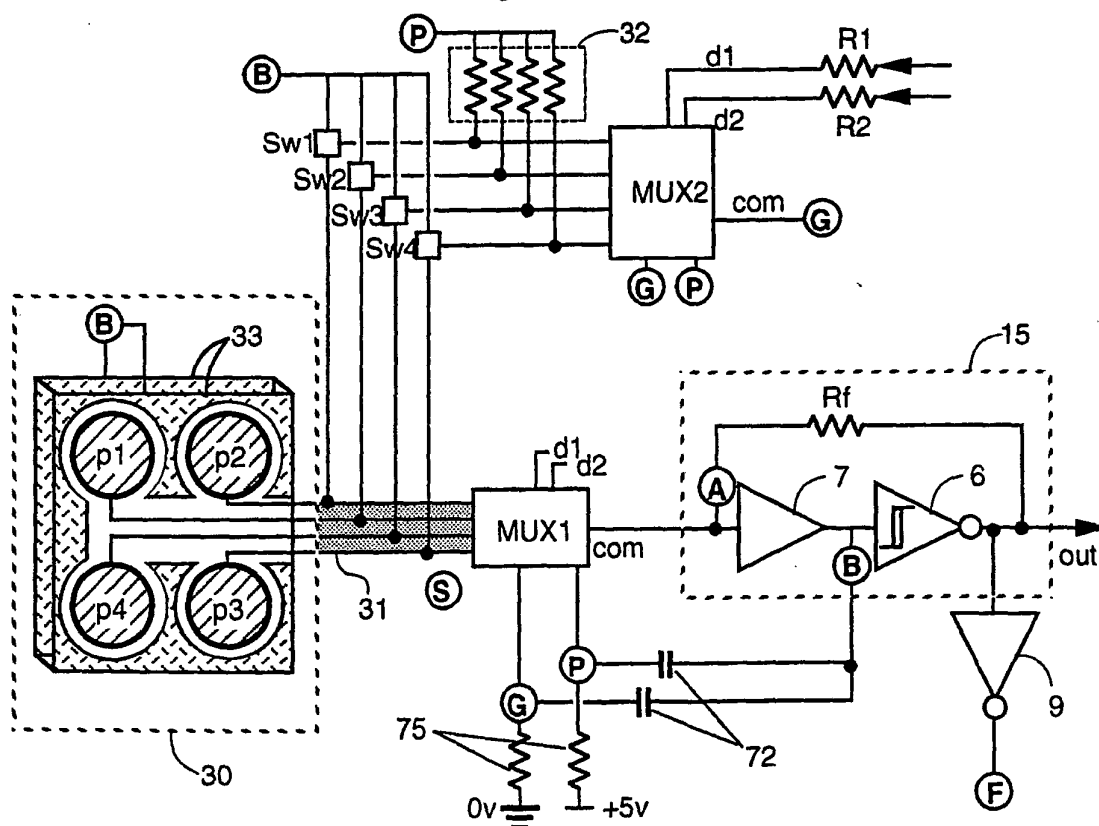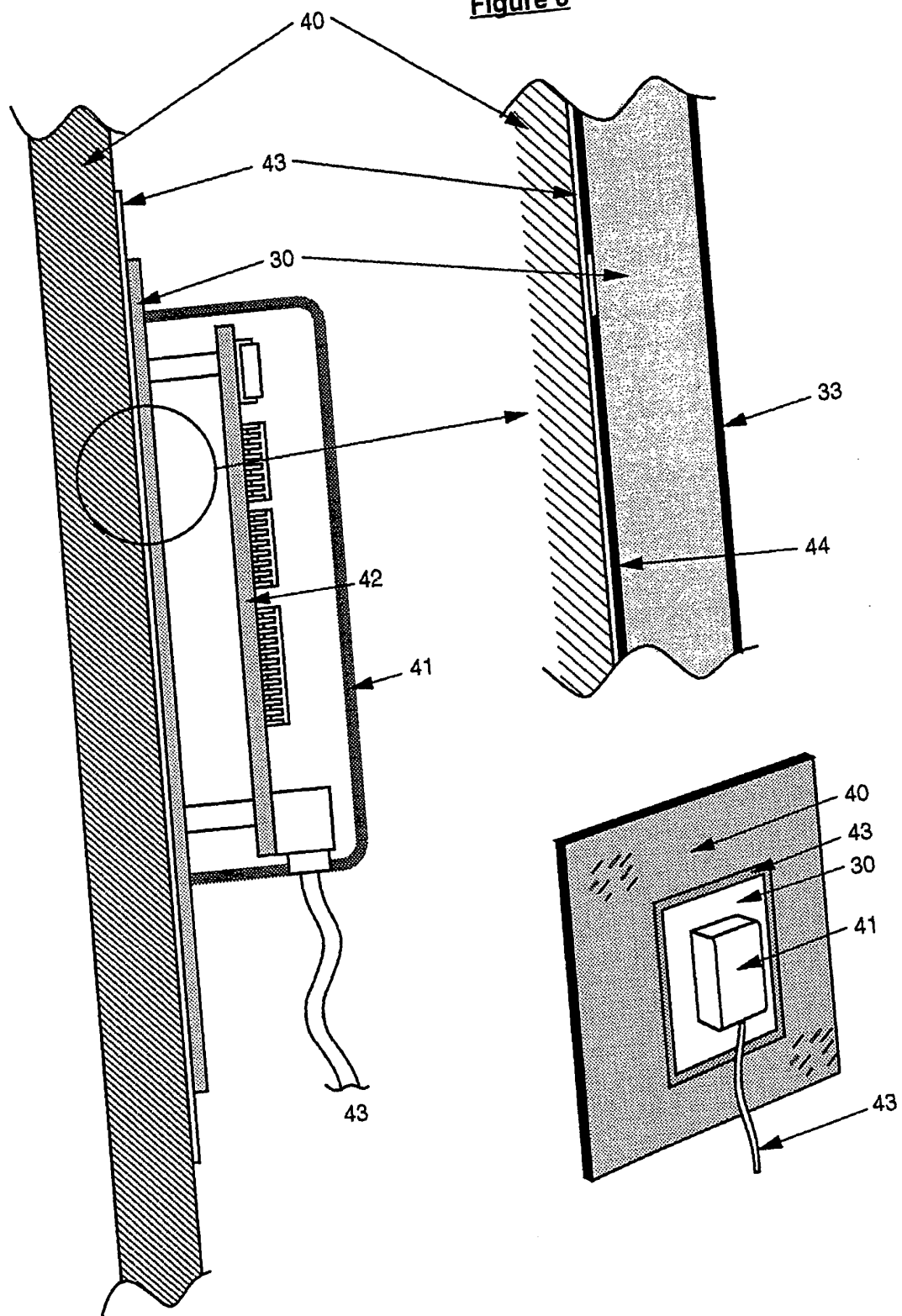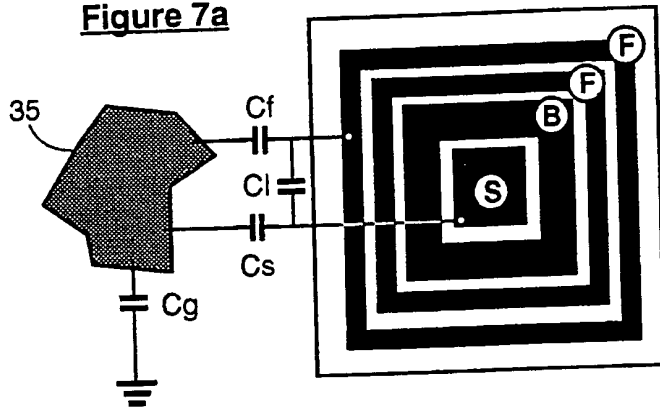
Figure 6

Figure 7a

Figure 7b

Figure 8a

Y axis

Z Axis

X axis
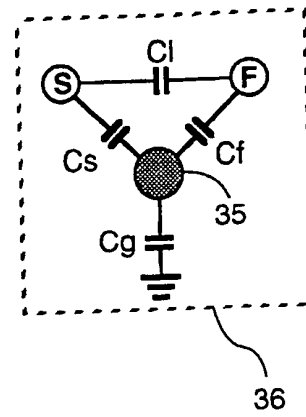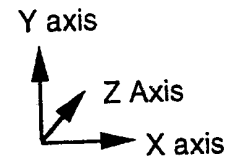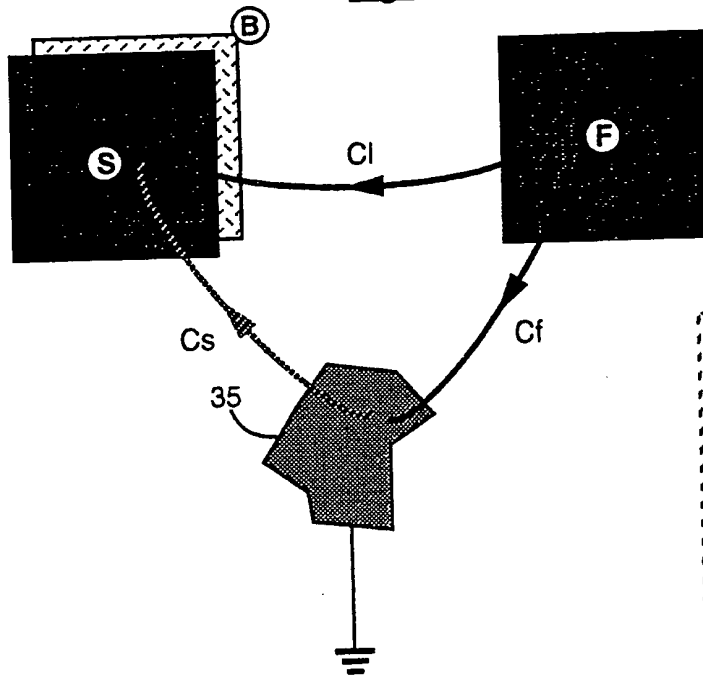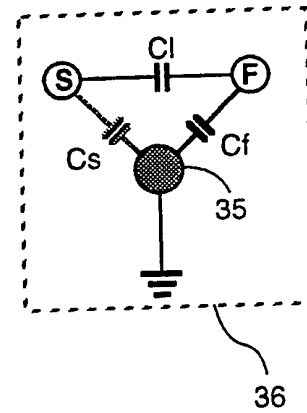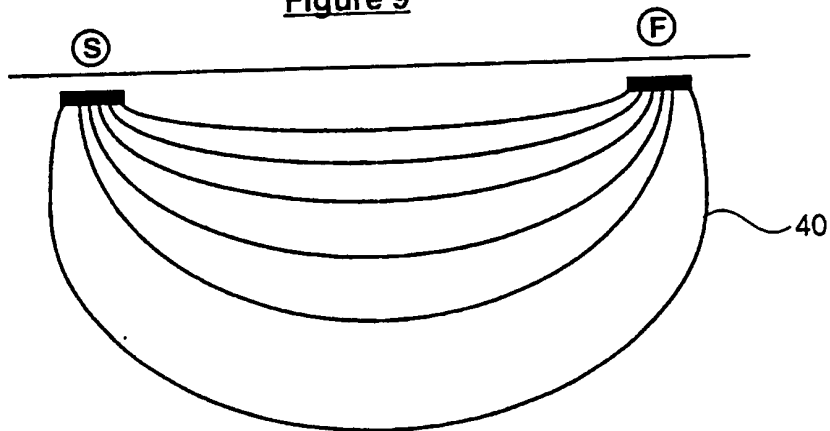
Figure 8b
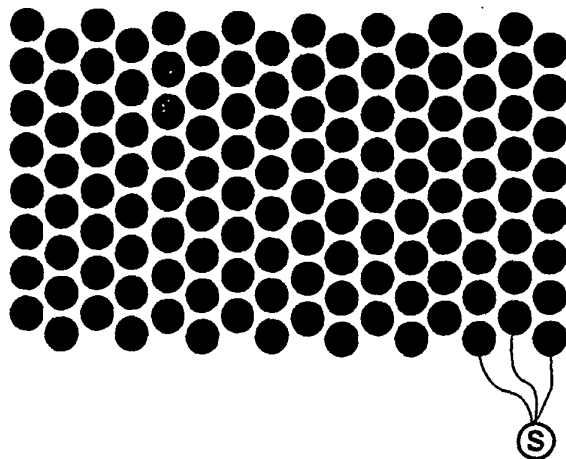
Figure 9

Figure 10

Figure 11
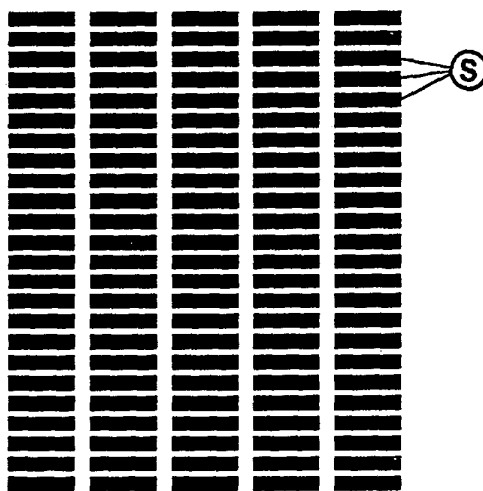
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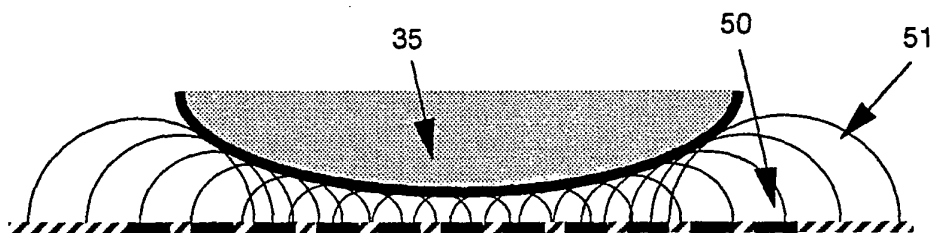
6/10

Figure 13
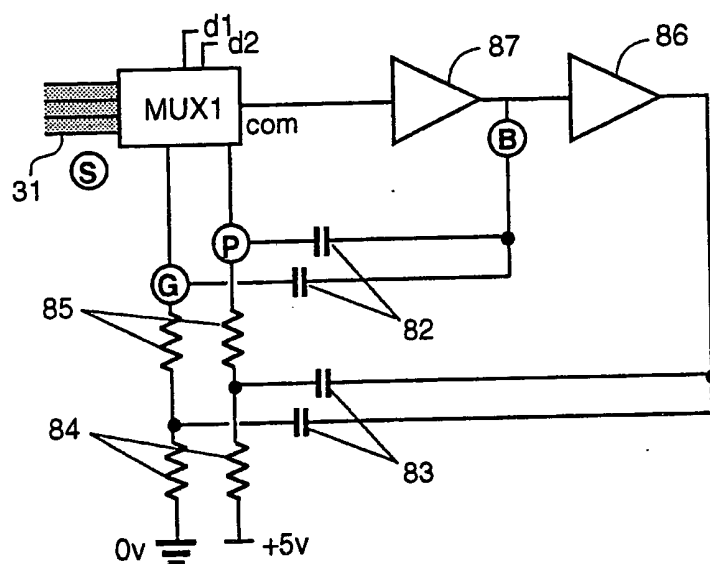
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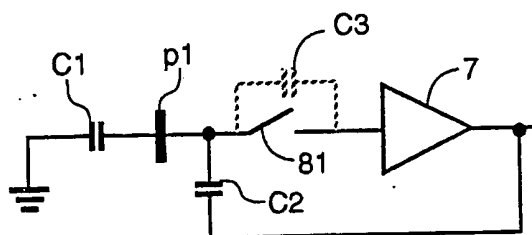
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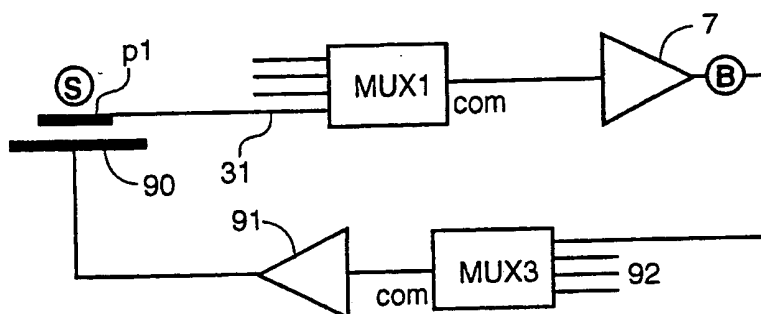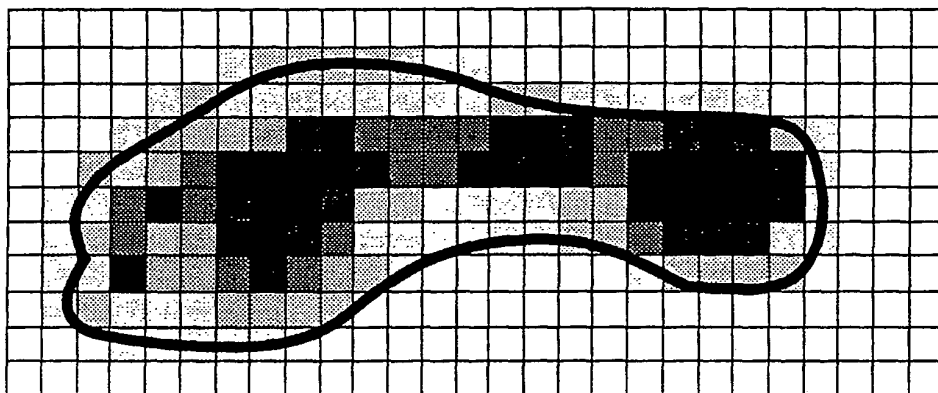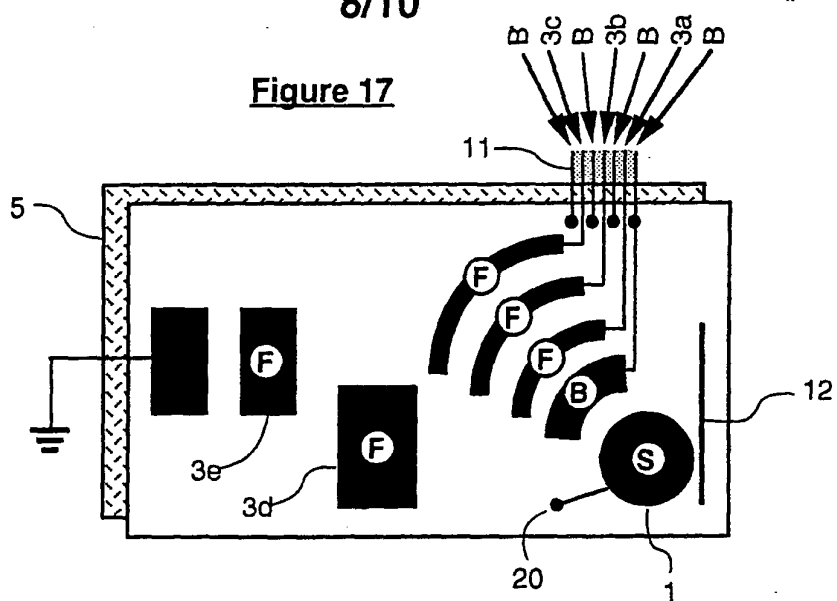
Figure 16

Figure 17

Figure 18
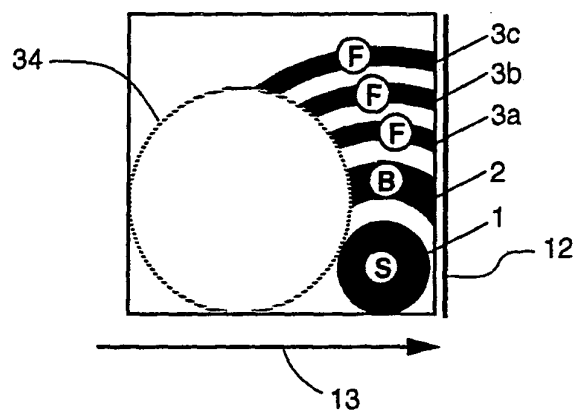
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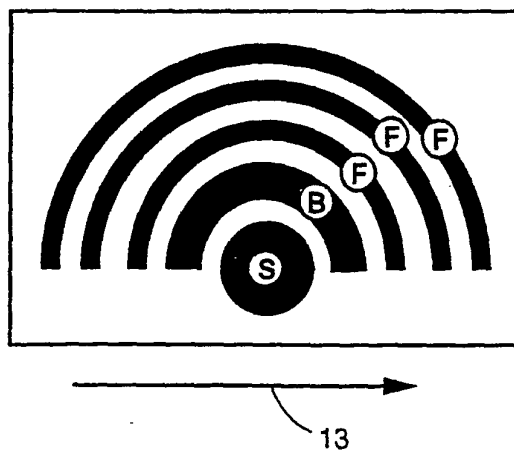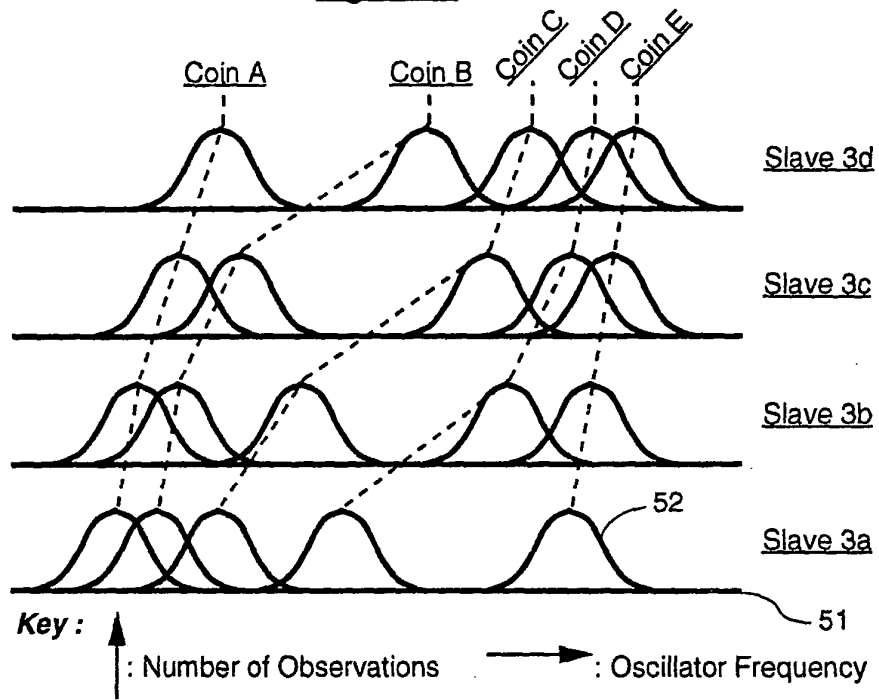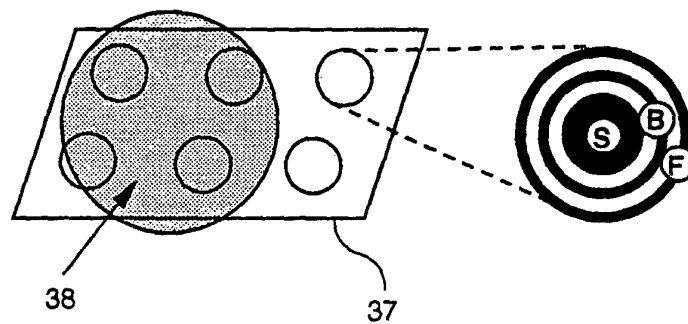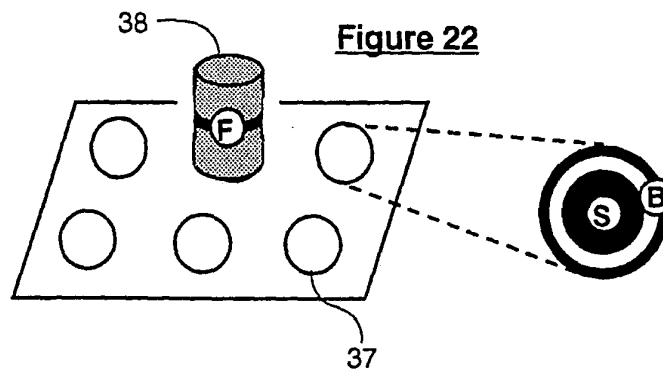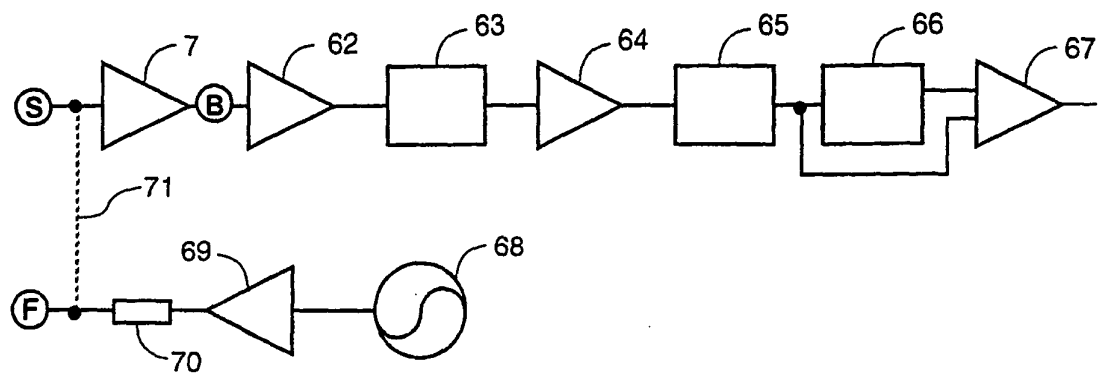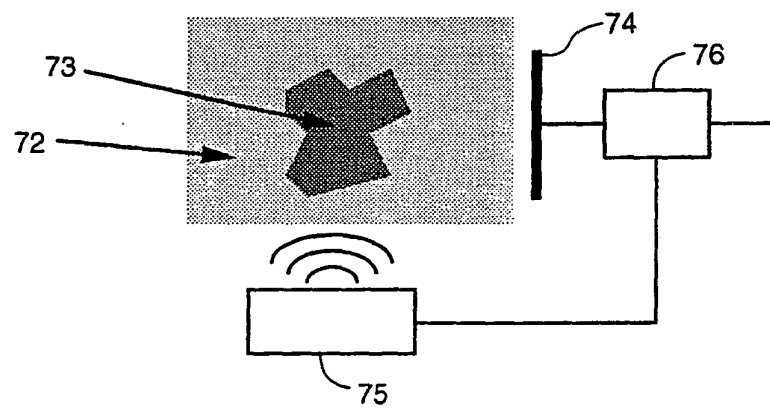
Figure 20

Coin A   Coin B   Coin C Coin D Coin E

Slave 3d

Slave 3c

Slave 3b

52

Slave 3a

51

Key :

↑ : Number of Observations   → : Oscillator Frequency

Figure 21

38   37

Figure 22

38

37

Figure 23

Figure 24

I. CLASSIFICATION OF SUBJECT MATTER   (If several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 G01B7/34;   G01B7/28

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	G01B

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category[o]	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
X,P	EP,A,0 425 823 (R.G.DOWER) 8 May 1991	1-4, 6-12, 14-19, 22,27,29
	see column 1 - column 11, line 34 see column 14, line 50 - column 20, line 4; claims 1-12; figures	
A		13,20, 21-26,28
A	EP,A,0 004 757 (GOULD INC) 17 October 1979 see the whole document	1-29
A	WO,A,8 801 747 (L.J.ROADES ET AL) 10 March 1988 see the whole document	1-29

[o] Special categories of cited documents :[10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
25 FEBRUARY 1992	0 5 MAR 1992
International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	BROCK T.J.

Form PCT/ISA/210 (second sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.   GB   9102021
                                          SA   53306

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 25/02/92

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